On the Frozen QCD Coupling

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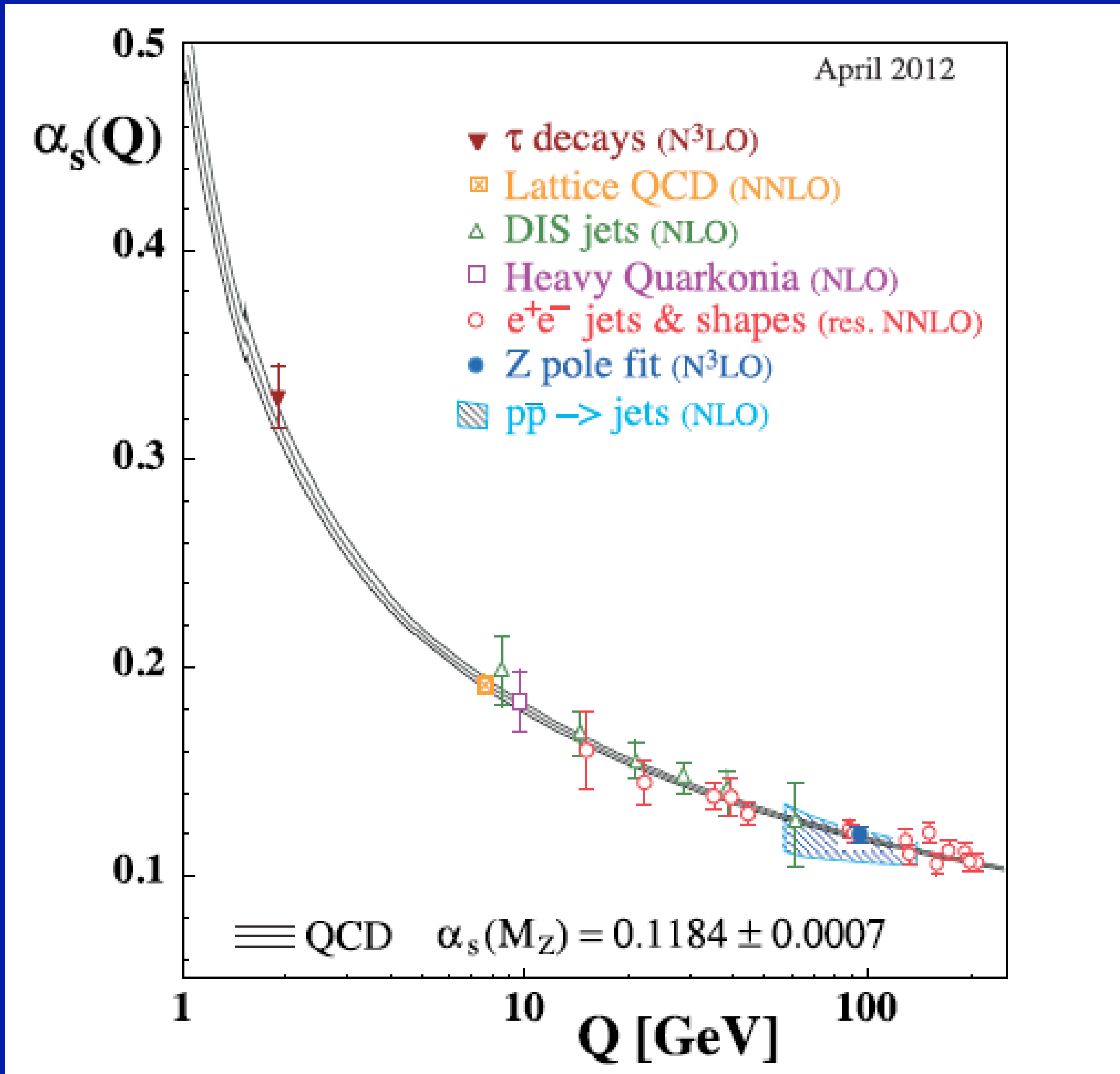
Motivation

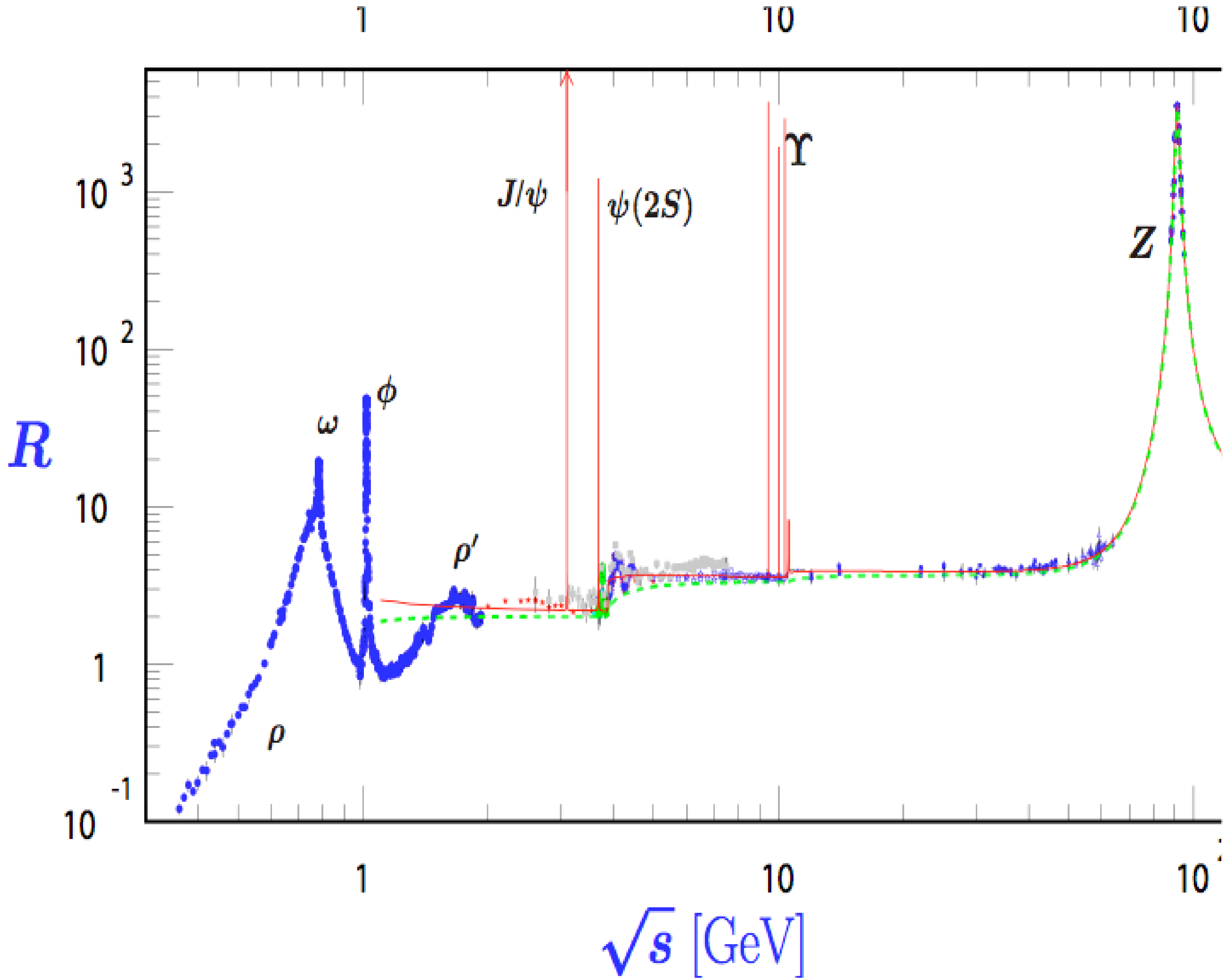
- The frozen QCD coupling is often used as an effective fixed coupling.
- Supposed to mimic running coupling effects and/or the lack of knowledge of alfa(s) in the infrared region.
- Usually its value is fixed from the analysis of the experimental data, for a given process. Scale of alfa(s) is unknown a-priori.



April 2012
$\alpha_s(Q)$
τ decays (N³LO)
Lattice QCD (NNLO)
DIS jets (NLO)
Heavy Quarkonia (NLO)
e⁺e⁻ jets & shapes (res. NNLO)
Z pole fit (N³LO)
p$\bar{p}$ –> jets (NLO)
QCD $\alpha_s(M_Z) = 0.1184 \pm 0.0007$
0.5
0.4
0.3
0.2
0.1
1
10
100
Q [GeV]

Quick history - infrared region

- e+e- annihilation, QCD and duality.



1
10
10
J/ψ
$\psi(2S)$
Υ
Z
ϕ
ω
ρ'
ρ
R
10^{3}
10^{2}
10
1
10^{-1}
1
10
$\sqrt{s}$ [GeV]

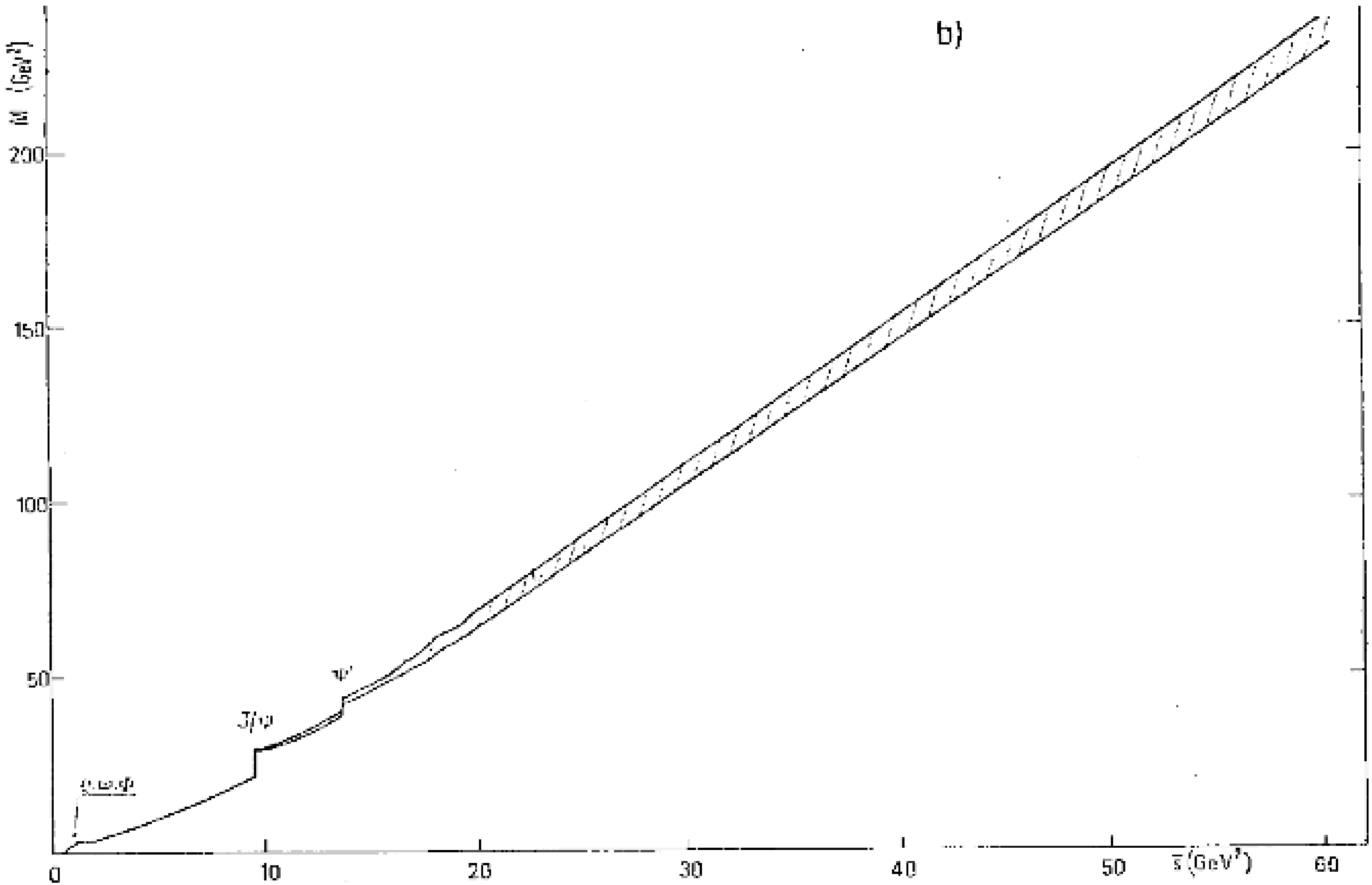
QCD:

$$R(s) = \sum_i Q_i^2 [1 + \frac{\alpha_s(s)}{\pi}]$$

Duality: compare moments

E.Etim,M.G.,1975

$$M(\bar{s}) = \int_{4m_\pi^2}^{\bar{s}} (ds) R_{experiment}(s)$$



“Frozen alfa(s)”: contin. of alfa(s) at low energy.

M.G., Penso, Srivastava, Phys.Rev.D,1980.

Quick history - infrared region

- e^+e^- annihilation, QCD and duality.

- Pt - distributions from QCD resummation.
  Curci, M.G., Srivastava, Phys.Rev.Lett. 1979

VOLUME 43, NUMBER 12 PHYSICAL REVIEW LETTERS 17 SEPTEMBER 1979

Coherent Quark-Gluon Jets

G. Curci
CERN, Geneva, Switzerland

and

M. Greco and Y. Srivastava[a]
Laboratori Nazionali di Frascati, Istituto Nazionale di Fisica Nucleare, Frascati, Italy

(Received 5 March 1979)

$$\frac{d^2P}{d^2K_\perp}=\frac{1}{2\pi}\int_0^\infty x_\perp dx_\perp J_0(x_\perp K_\perp)\exp\left\{-\frac{2I(\epsilon)}{\pi}\int_0^{Q/2}\left(\frac{dk_\perp}{k_\perp}\right)\bar{\alpha}(k_\perp)[1-J_0(x_\perp k_\perp)]\right\}$$

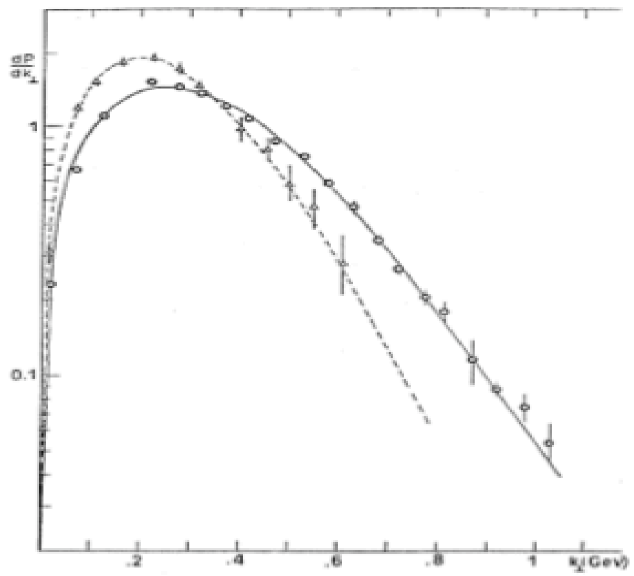


FIG. 1. Normalized $\sigma^{-1}d\sigma/dk_\perp$ vs $k_\perp$ for $Q=3$ GeV (triangles) and 7.5 GeV (circles) SPEAR single inclusive data from Ref. 6. Our results are given by the dashed line for 3 GeV and by the solid line for 7.5 GeV.

OBSERVATION OF QCD EFFECTS IN TRANSVERSE MOMENTA OF e^+e^- JETS

PLUTO Collaboration

$$\frac{dP}{dK_\perp} = K_\perp \int_0^\infty \xi d\xi J_0(\xi K_\perp) \exp\left(-\frac{16}{3\pi} \int_0^{\xi_\perp} \frac{dq_\perp}{q_\perp} \ln(Q/q_\perp)\, \alpha_s(q_\perp)[1 - J_0(\xi q_\perp)]\right)$$

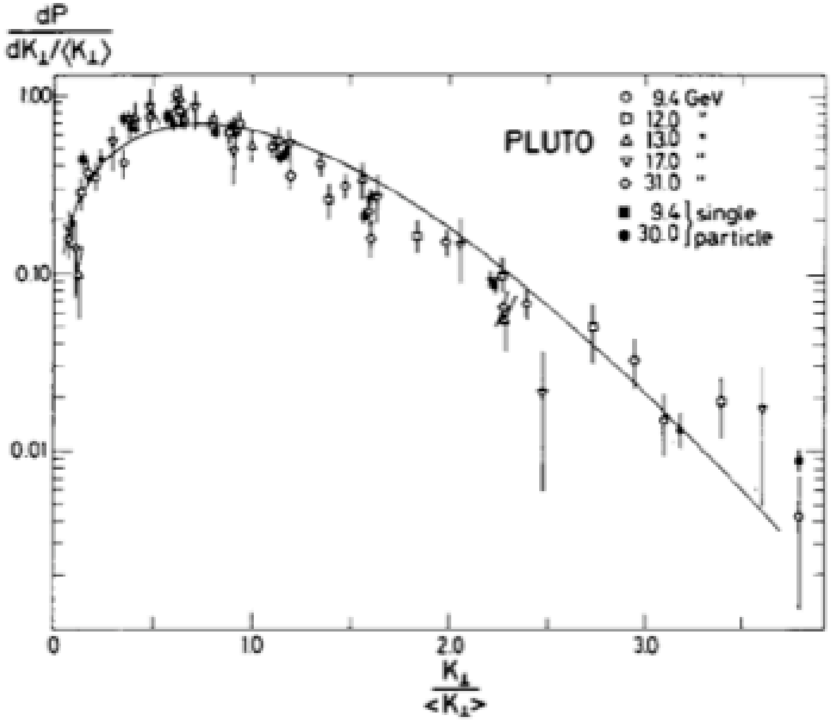


Fig. 2. Distributions of the reduced variable $K_\perp/\langle K_\perp\rangle$ at the quoted c.m. energies. The full line is the theoretical expecta-

Quick history - infrared region

- e+e- annihilation, QCD and duality.
- Pt -distribution from QCD resummation.
- Power-behaved contribs. to hard processes in QCD from non perturbative effects.
  Dokshitzer, Marchesini and Webber, Nucl.Phys. 1996
- …..

Quick history - perturb. region

- Complicated calcs. --> alfa(s) fixed
  Which scale?
- Leading Log. Approximations
- Summing double/single logs
- Small x, DGLAP, BFKL

Recent analysis - E.P.J.Plus 128(2013)

Ermolaev,M.G.,Troyan

- Novel way to define frozen couplings, independently from experiments.
- Three kinds of couplings:
  DLA - spacelike arguments
  DLA - timelike arguments
  SLA (ex. BFKL)
- Our estimates agree with results available in literature.

Simple mathematical argum.

- Consider: $$V = \int_a^b dx g(x) f(x)$$

(A) f(x) varies much faster than g(x)

$$V \approx V_A = g(x_0) \int_a^b dx f(x),$$

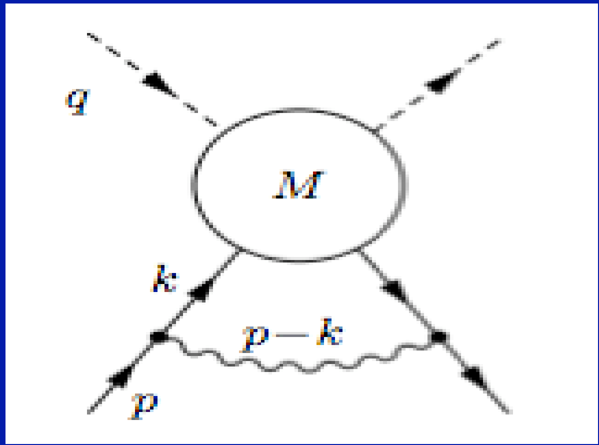
(B) f(x) and g(x) vary similarly

$$V \approx V_B = \bar{g} \int_a^b dx f(x),$$

$$\bar{g} = \frac{1}{b-a} \int_a^b dx g(x).$$

DIS structure functs. from evolution equations

$$M = M_{Born} + M \otimes M_{Born}.$$



Leading DL contribs. at small x

$$A(x, Q^2) = \int d\beta \frac{dk_\perp^2}{k_\perp^2} M\left(x, Q^2, w\beta, k_\perp^2\right)\alpha_{eff}$$

$$w = 2pq, Q^2 = -q^2, x = Q^2/w$$

$$\alpha_{eff} \approx \alpha_s\left(k_\perp^2/\beta\right)$$

---->

$$\alpha_s^{DL}(\mu) = \frac{1}{b}\frac{\ln(\mu^2/\Lambda^2)}{\left[\ln^2(\mu^2/\Lambda^2) + \pi^2\right]}$$

Ermolaev, Troyan,PL 2008

Which scale?

Principle of minimal sensitivity Stevenson 1981

$$\frac{d\alpha_s^{DL}(\mu_0)}{d\mu} = 0.$$

- (i) Factorized gluon timelike (DIS)

$$\alpha_s^{DL}(\mu_0) = \frac{6}{11N - 2n_f}. = 0.24$$

- (ii) Factorized gluon spacelike (e+e- , DY)

$$\tilde{\alpha}_s^{sud} = \frac{12}{11N - 2n_f}. = 0.48$$

- Agrees with previous e+e- estimates

Further check with intercepts in DIS

- Regge asymptotics calculated in DLA with fixed alfa(s) for F_1^{NS} g_1^{NS}
  Ermolaev,Manaenkov,Ryskin,Bartels 1996
- Same calculation taking into account running alfa(s) effects
  Ermolaev,M.G.,Troyan 2000-'01-'04
- Two results agree within 10-15%
  Frozen coupling --> larger intercepts

Frozen coupling for SLA

- Well-known ex. BFKL Pomeron (LO, NLO). Scale fixed a posteriori Brodsky,Fadin,Kim,Lipatov 1999

$$\Delta^{P}_{NLO} \approx A\alpha_s^{SL}\left(1 - B\alpha_s^{SL}\right).$$

(i) Apply PMS $\frac{d\Delta^{P}_{NLO}}{d\alpha_s} = A(1 - 2B\alpha_s) = 0.$ --> $\alpha^{SL}_{PMS} = 1/2B \approx 0.08.$

(ii) Define averaged coupling

$< \tilde{\alpha}_{eff} >= \frac{1}{l}\int dl\alpha_{eff}(l)$ --> $\alpha_s^{SL} \sim 0.1.$

-- Agrees with previous estimates

Conclusions

- Novel way to define the frozen QCD couplings and fix their value.
- It depends on the type of leading logs. DLA/SLA, and space-/time-like argums.
- Insight in the infrared region.
- Our estimates, based on PMS, agree with previous results within a few %, with no use of experimental data.

THANK YOU